Natural enemies and their use in the bio-control of insect pests in Taiwan

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Abstract

This paper describes the progress of research, development and application in the biological control of crop pests in Taiwan, including survey and identification of natural enemies, conservation and augmentation of the indigenous natural enemies, the introduction of exotic parasitoids and predators, mass production of natural enemies, and selection of crops.

Introduction

Biological control of insect pests has long been recognized as one of the traditional/natural methods of pest control and has been used to some extend by our farmers for some time in Taiwan. Since the synthetic pesticide been rapidly developed and being used effectively and extensively for pest control, the application of control practices by biological, cultural, and physical methods had lost their comparable advantage in modern farming with high input of low cost of pest control by agrochemicals. Due to the warm and humid climate in Taiwan, pests are subject to thrive and cause considerable crop loss if not timely checked and control practices not properly applied. However, there were more negative impacts resulted from extensive chemical pesticide use, causes resistance of pests to insecticides and environmental pollution as well as bringing unwanted pesticide residue to crops, not to mention abruptly interrupted the survival of natural enemies and functionality of bio-control. All together, these factors exacerbate the declining of the agricultural and ecological equilibrium. In view of the natural roles of biological control in pest control, research efforts in gaining more practical application in natural enemies has always been sought as alternative solution in finding ways to be fit in as an integral part of IPM strategy in Taiwan. For nearly a century, Taiwan has made noticeable progress in the field of biological control of crop pests. This paper reviews the research, development and application in biological controls of insect pests including predators and parasitoids, and the introduction and breeding of the natural enemies and their utilization in Taiwan.

Survey and application of natural enemies

Rice insect pests and their natural enemies

In the early 20th century, the Forestry Experimental Station of Taiwan Government-General first made general surveys of insect pests and their natural enemies such as predators and parasitoids on sugarcane and cotton. Around the 1930s, Taiwan Sugarcane Experimental Station (the former Taiwan Sugar Corporation) started the research on the biology of insect pests including life cycles and food chains on sugarcane fields were studied. In addition, Taiwan Agricultural Research Institute (TARI) expanded its investigation to cover the insect pests and their natural enemies

including predatory bugs and parasitic wasps of pests on crops, vegetables, and fruits. Since then many insect pests have been found on rice, of which the three important one were: rice green leafhopper (*Nephotettix cincticeps* (Uhler) (Hemiptera: Cicadellidae)), brown planthopper (*Nilaparvata lugens* (Stål)), and leaf roller (*Cnaphalocrocis medinalis* Guenee, (Lepidoptera: Pyralidae)) along with their natural enemies had been studied extensively by Chiu (1978). Totally, 21 parasitoids and 17 predators were found. Two egg parasitoides (*Anagrus* sp. and *Gonatocerus* sp., (Hymenoptera: Mymaridae) and two predatory spiders (*Lycosa pseudoannulata* Boes. & Str. (Araneae: Lycosidae) and *Oedothorax insecticeps* (Boes. & Str.) (Araneae: Micryphantidae) are most common and important natural enemies for rice green leafhopper and brown planthopper. There were 25 species of natural enemies of the rice leaf roller found in Taiwan (Chen and Chiu 1983). Among parasitoides, *Trichogramma chilonis* Ishii (Hymenoptera: Trichogrammatidae) and *Apanteles* sp. (Hymenoptera: Braconidae) were found to be more abundant in paddy fields.

Soybean insect pests and their natural enemies

The soybean leaf roller, *Hedylepta indicata* (Fabricius) (Lepidoptera: Pyralidae), has been observed as a very common pest in soybean fields in Taiwan. There were 13 parasitoids of the soybean roller recorded by Chien et al. (1984), of which one egg parasitoid, seven larval parasitoids, three larval-pupal parasitoids, and two pupal parasitoids were recorded. It was found that *Apanteles inquisitor* (Wilk.) was the predominant wasp.

Sweet-potato insect pests and their natural enemies

Chiu et al. (1978) surveyed the parasitoids of lepidopterous insects of sweet-potato in Taiwan. Twenty-three species of parasitoids were reared from eleven species of lepidopterous insects of sweet-potato. Among them, *Apanteles bisulacata* Cameron may be considered as one of the most promising biological control agents of *Ochyrotica concursa* Walsinghan (Lepidoptera: Pterophoridae) in Taiwan. The percentage of parasitism of the moth ranged from 10.5% to 71.4% through the year.

Vegetable insect pests and their natural enemies

Natural enemies of pests on vegetables had been surveyed. *Apanteles plutellae* Kurdjumov has been considered as one of the promising biological control agents of the diamondback moth (*Plutella xylostella* (Fabricius) (Lepidoptera: Plutellidae)). The parasitism of the diamondback moth could reach 37.5% (Wu 1968, Chiu and Chien 1972). Parasitoids of armyworm, *Spodoptera litura* Fabricius (Lepidoptera: Noctuidae) were surveyed by Chiu and Chou (1976). One species of egg parasitoid and nine species of larval parasitoids were found, of which *Snellenius manilae* (Ashmead) (Hymenoptera: Braconidae) is the most common parasitoid. The parasitism of the armyworm ranged from 5.3% to 43.9%.

Fruit insect pests and their natural enemies

The fauna of insect pests on citrus and their natural enemies had been surveyed by Lo and Chiu (1986) for three years (1981-1984). Fifty-three insect pests and one hundred natural enemies had been found during the survey. The lac insect, Kerria lacca (Kerr) (Hemiptera: Kerridae), was a serious pest of the fruit trees including longan, litchi, and sugar apple in Taiwan. A general survey

of the natural enemies of the lac insect was conducted by Chiu et al. (1981). A total of five parasitoids and six predators were found.

Bio-control as part of integrated pest management

More attention has been given to the integrated pest control since the 1960s. Early observation on the decrease or elimination of the usage of chemical pesticides in paddy fields showed increase population of natural enemies, such as predatory spiders (Chiu 1978, Chen and Chiu 1979). Rice is a staple crop it has always been a major concern on the studies on the outbreaks of insect pests and the fluctuation of the composition of natural enemies in Taiwan. Thus, chemical pesticides registered for rice insect pest control must examined in the bio-safety in low toxicity to meet the requirement of application for a range of target natural enemies in paddy field. The improper or overuse of pesticides certainly would endanger the survival and damage the natural population balance of the natural enemies. Thus, IPM has been considered a major approach along with the use of selected low toxicity pesticides for insect pest control practices in Taiwan. Since 1970, toxicity of various insecticides to natural enemies has been conducted prior registration and a profile of lower toxicity insecticides has been established, such as for the green lacewing, *Chrysopa boninensis* Okamoto (Wu and Lo 1988), larvae of *Mallada basalis* (Walker) (Neuroptera: Chrysopidae) (Tzeng and Kao 1996); predators of rice-hoppers (Chiu and Cheng 1976) and other rice pests (Chu et al. 1976); the parasitoid (*Apanteles plutellae*,) of the diamondback moth (Chang 1974), and the predator (*Cryptolaemus montrouzieri* Mulsant, Coleoptera: Coccinellidae) of the citrus mealybug (*Planococcus citri* (McGregor), Hemiptera: Pseudococcidae) (Hwang et al. 1986). Improvement of the cultivation practices and field environment have been demonstrated beneficial to the existence and survival rate of natural enemies. Take spider mites on fruit trees for instance, the presence of certain weeds in orchards could effectively maintain populations of their natural enemies. The weeds grown around paddy fields also help conserve the predatory spiders. Moreover, increase of the space between rows of rice plants also increased the density of spiders (Chiu and Chen 1981). Many factors affect the populations of pests in agricultural ecological systems where natural enemies are considered critical. Moreover, conservation of natural enemies has become possible through these researches.

Introduction of natural enemies

When pests become out of control and no indigenous natural enemies are present, the introduction of natural enemies had been taken into consideration as a means of pest control. In 1909, the production of citrus were serious threatened by the cottony cushion scale (*Icerya purchasi* Maskell, Hemiptera: Margarodidae) in Taiwan. Therefore, the Vedalia ladybeetle (*Rodolia cardinalis* Mulsant) was first introduced from New Zealand for the purpose of controlling the cottony cushion scale. The cottony cushion scales were quickly brought under control soon after the mass release of the ladybeetle and its population established in orchards. Success of biological control was officially announced within three to four years. It became one of the most successful cases recorded in early history of biological control in Taiwan (Lo and Tao 1966). Other ladybeetles like *Rodolia pumila* Weise, and *Cryptolaemus montrouzieri* were also introduced for the same purpose. The population of the latter two had since been established and the species are becoming quite common

in Taiwan. Biological control of insect pests of sugarcane by introducing alien ladybeetle, *Coelophora saucia* Mulsant (Coleoptera: Coccinellidae), was conducted in 1924 to control aphides. And the entomopathogenic fungus, *Metarhizium anisopliae* (Metchnikoff.) was introduced from Hawaii for the control of *Alissonotum impressicolle* Arrow (Coleoptera: Scarabaeidae) in 1931. However, there were failures in some cases. For example, the importation of parasitic wasps and flies like *Telenomus theophilae* Wu and Chen (Hymenoptera: Scelionidae) failed to establish due to the difficulties of reproduction.

The salient features of bio-control cases in Taiwan

Bio-control of coconut leaf beetle

The coconut leaf beetle (*Brontispa longissima* (Gestro), Coleoptera: Chrysomelidae) was invaded and found in Pingtung, Taiwan in 1975. The invasive beetle seriously damaged coconut trees and spread all over Taiwan within six months. In 1983, the coconut leaf beetle parasite, *Tetrastichus brontispae* Ferriere (Hymenoptera: Eulophidae) was imported from Guam. A total of 106 releases of about 143,082 adults were released to Kaohsiung, Pingtung, Taitung, Hualien, Chiayi, Yunlin and Taipei from January, 1984 throught June, 1986. Populations of the wasps were established soon and the coconuts recovered. This has become one of the most successful cases of biological control in Taiwan (Chiu et al. 1985, 1988).

Bio-control of citrus psyllids

Citrus psyllid (*Diaphorina citri* Kuwayama, Hemiptera: Psyllidae) transmits citrus diseases, noticeably citrus greening, also called Citrus Huanglongbing (HLB). Its natural enemiy Eulophid wasp, *Tamarixia radiate* (Waterston) (Hymenoptera: Eulophidae) was imported from Reunion in 1080s and were released after mass propagation into hedges in orchards of orange-jasmine for controlling citrus psyllids in the span during 1984 to 1988. The wasps were observed and gradually established spreading all over and worked well on psyllids (Chien et al. 1988).

Bio-control of crucifer vegetables insect pests

The diamondback moth has long been known as one of the most destructive pest of crucifers throughout in the Asian tropics and Pacific region. The use of two larval parasitoids, *Diadegma eucerophaga* Horstmann (Hymenoptera: Ichneumonidae) and *Apanteles plutellae* (collected locally), which were introduced from Indonesia in 1970s were investigated in the laboratory, greenhouse, and limited field trails before introduction trials of releasing these parasitoids into farmers' fields in Taiwan. In a field study in which cabbage planting was confined to a large net house, parasitism by *D. eucerophaga* of diamondback moth increased from 13.1% one month after planting to 65.4% just before harvest. Consequently, the cabbage yield was doubled compared with the control plot into which no parasite had been introduced (Talekar et al 1990). Despite repeated releases, *D. eucerophaga* failed to become established in the lowlands and slightly elevated areas below 700m. However, it is established in highland crucifer-growing areas in Taiwan at elevations of 1000m and above. Parasitism in such areas is high and diamondback moth is not considered a serious pest any more at higher altitudes (Talekar et al. 1990).

There are 12 alien insect- and mite pests which invaded Taiwan since 1975 (Table 1, Lo

2002). Among them, coconut leaf beetle, pear phylloxerid (*Aphanostigma piri* (Cholodovski), Hemiptera: Phylloxeridae), American leafminer (*Liriomyza trifolii* (Burgess), Diptera: Agromyzidae), spiraling whitefly (*Aleurodicus dispersus* Russell, Hemiptera: Aleyrodidae), rice water weevil (*Lissorhoptrus oryzophilus* Kuschel, Coleoptar: Curculionidae), and two-spotted spider mites have been stayed put and often caused serious damage to crop production. Since 1970, a total of 23 natural enemies have been introduced into Taiwan (Table 2). However, the rate of success for their establishment in controlling pests was only accounted for 30.4% (Lo and Chen 1995, Lo 2002). Further studies of factors being introduced of natural enemies include their biological characteristics, local weather, and local habitat environments need to be documented prior to their introduction.

The mass production and release of natural enemies

The densities of natural enemies in natural environments usually are low. In order to increase their ability to suppress pest populations, mass production and release of them to crop fields become necessary. Therefore, mass rearing techniques of both target insect pests and their natural enemies need to be established to pave the way lead to sound biological control program.

Case story of the mass production of *Trichogramma* wasps for bio-control of sugarcane- and Asian corn borers

Trichogramma wasps are egg parasites of certain sugarcane borers such as *Argyroploce schistaceana* (Snellen), *Chilotraea infuscatella* (Snellen), and *Proceras venosatus* Walker (Lepidoptera: Pyralidae). Due to its easy mass production, the rice moth *Corcyra cephalonica* Stainton (Lepidoptera: Pyralidae), a pest of stored grain has been used as a substitutive host. The mass produced rice moths were then used for the mass rearing of *Trichogramma* wasp. Thus, *Trichogramma australicum* Giracult have been developed since 1960s (Chen 1963), leading to the Taiwan Sugar Corporation to its releasing program of *Trichogramma* wasps on a large scale to increase the rate of parasitism of sugarcane borers (Cheng et al. 1978). The release spots received 105,800-378,000 parasites per hectare. The egg parasitism was determined to be 0.0-34.5% for the control, but as high as 4.8-82.5% for the release plots. The “dead-hearts” of the young canes in the release plots were decreased by 37.0-100.0% in comparison with the corresponding controls. Ever since, the mass production center for *Trichogramma* wasps was established by the Taiwan Sugar Corporation to extend the release program to larger areas. For instance, 55,809 hectares of sugar cane fields have been covered with *Trichogramma* release during the year of 1982-1983 (Cheng 1986). Mass production of *Trichogramma* wasps had also been used for the of Asian corn borer *Ostrinia furnacalis* (Guenée) (Lepidoptera: Pyralidae) (Cheng et al. 1995). This decreased the use of pesticides and reduced the pesticide residue problems on corn.

Mass releasing of predatory mites for bio-control of spider mites

The use of predatory mites to control pest spider mites has also been attracted great attention for the protection of fruits and vegetables. The mass rearing techniques of *Amblyseius womersleyi* Schicha and *A. longispinosus* (Evans) (Acari: Phytoseiidae) had been developed by the National Chung Hsing University (Shih 1985, Shih and Wang 2002) and the Taiwan Agricultural Research

Institute (Lo et al. 1984), respectively. Both of the predatory mites releasing program have been applied regularly to some extend in star-fruit orchards, tea plants, mulberries and strawberries for controlling Kanzawa spider mites (*Tetranychus kanzawai* Kishida, Acari: Tetranychidae). The results indicated that one release of predators (release ratio between predator and prey was 1:30) at 100,000 individuals per hectare was sufficient to control spider mite populations for at least one month showing a success rate of 95 out of 100. On the other hand, chemical alternative required weekly sprays to achieve an equal suppression of spider mite population. The ratio of cost of biological- and chemical control was 1 to 3. The introduction and mass release of *Amblyseius fallacis* Garman and *Phytoseiulus persimilis* Athias-Henriot (Lo et al. 1990) have demonstrated effectively in eliminating the invasive two-spotted spider mites (*T. urticae* (Koch)) and European red mite (*Panonychus ulmi* (Koch)) on papaya trees, pear trees, mulberries, and strawberries.

Lacewings are widely use as effective pest predators

Lacewings (Neuroptera: Chrysopidae) are the most widely used natural enemies in the world. TARI created micro-encapsulated food to replace the traditional food, eggs of *Corcyra cephalonica* Stainton, to improve the efficiency of production of the lacewing (*Mallada basalis* (Walker)) (Lee 1994). The release of lacewings lowered the population of citrus red mites（*Panonychus citri* McGregor） (Wu 1992) and citrus leafminer (*Phyllocnistis citrella* Stainton, Lepidoptera: Gracillariidae) (Wu 1995) in orange orchards. It also lowered the population of citrus mites and citrus mealy bugs (*Planococcus citri*) on jojobe in net houses (Hao 2002), Kanzawa spider mites and two-spotted spider mites on strawberries (Chang and Huang 1995), Kanzawa spider mites (Hsiao 2003) and tea red spider mites (*Oligonychus coffeae* Nietner) (Hsiao 2002) on tea plants, Kanzawa spider mites on papaya trees (Hao 2002), as well as whiteflies (*Bemisia argentifolii* Bellows and Perring, Hemiptera: Aleyrodidae) (Lo et al. 2002) on canteloupes, and aphids (*Aphis gossypii* Glover, Hemiptera: Aphidae) (Lu and Wang 2006) on sweet peppers in net houses. The suppression effect varied though, according to different crops and species of insects.

Flower bug is a promising bio-control agent

The flower bugs, *Orius* species (Hemiptera: Anthocoridae) is a predator which prefer thrips and aphids as its prey. They are applied as biological control agents around the world. In Taiwan, the flower bug (*Orius strigicollis* (Poppious) is the most promising biological control agent. It has been mass reared with bean sprouts (*Glycine max* Merr.) as plant food and ovipositional substrate and eggs of flour moth (*Ephestia cautella* (Walker), Lepidoptera: Pyralidae) as prey by the Taiwan Agricultural Research Institute and Tainan District Agricultural Improvement Station (Wang 1994, Wang et al. 1999, 2002). The flower bugs have successfully lowered the population of bean thrips (*Megalurothrips usitatus* (Bagnall), Thysanoptera: Thripidae) on red beans, as well as *Thrips palmi* Karny on eggplants, melons and bell peppers with the experiments conducted in central and southern Taiwan. Another predatory stink bug, *Eocanthecona furcellata* (Wolff) (Hemiptera: Pentatomidae), has been mass reared by the Miaoli District Agricultural Improvement Station and supplied with larvae of *Chrysomyia megacephala* Fabricius (Diptera: Calliphoridae) as food (Chang 2002, Chang and Hsieh 2001). It could effectively control pest moths and butterflies such as the white cabbage butterfly (*Pieris rapae crucivora* Boisduval (Lepidoptera: Pieridae)), the

armyworm, the diamondback moth, and the beet armyworm (*Spodoptera exigua* Hubner (Lepidoptera: Noctuidae)).

In order to meet the rising demands for food safety and organic farming, the application of biological control of insect pests is expanding led to more natural enemies are presently being produced for sale. So far, lacewings, *Trichrogramma* wasps, *Orius* flower bugs, predator mites, and stink bugs are available in supply to farmers' need. This is a promising scenario in the development and promotion of biological control. Search of pest more natural enemies are expected to produce and be released for practical application to benefit the development of biological pest control.

Conclusion

In Taiwan, the research and development of biological control in some academies and agricultural research institutions have been carrying on a long way and remain strong to search for expanding application of bio-control as part of IPM system. With our continuous studies and research perspectives, the application of biological control will continue to add to new frontiers for crop insect pest control in tropical agricultural environment toward sustainable crop production and food safety.

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Common name	Scientific name	Year
Coconut leaf beetle	*Brontispa longissima*	1975
Vienna spider mite	*Tetranychus viennensis*	1976
Pear phylloxerid	*Aphanostigma piri*	1979
European spider mite	*Poanonychus ulmi*	1979
Two-spotted spider mite	*Tetranychus urticae*	1979
Jumping plantlice	*Heteropsylla cubana*	1985
Banana skipper	*Erionota totus*	1986
American leafminer	*Liriomyza trifolii*	1988

Table 1. The records of invasive insect and mite pests in Taiwan from 1975 to 2000

Greenhouse whitefly	*Trialeurodes vaporariorun*	1988
Spiraling whitefly	*Aleurodicus dispersus*	1989
Rice water weevil	*Lissorhoptrus oryzophilus*	1990
Bulb mite	*Rhizoglyphus echinopus*	2000

Table 2. Records of introduced natural enemies for control insect and mite pests (1971-1990)

Year	Introduced natural enemies	Preys	Origin	Result
1971	*Opius importatus*	Beanflies	Hawaii	F
1971	*Opius phaseli*	Beanflies	Hawaii	F
1973	*Apanteles vestalis*	Diamondback moth	Holland	F
1973	*Diadegma fenestralis*	Diamondback moth	Holland	F
1974	*Apanteles glimeratus*	Imported cabbageworm	Japan	E
1983	*Tetrastichus brontispae*	Coconut leaf beetle	Guam	S
1983	*Tamarixia radiate*	Citrus psylla	Reunion	S
1983	*Trissolcus basalis*	Green stinkbug	Hawaii	E
1983	*Amblyseius californicus*	Two-spotted spider mite	Hawaii	E
1983	*Typhlodromus occidentalis*	Two-spotted spider mite	US	F
1984	*Trighogramma nubilale*	Asian corn borer	US	F
1985	*Amblyseius fallacies*	Two-spotted spider mite	US	S
1985	*Diadegma semiclausum*	Diamondback moth	Indonesia	E
1987	*Cotesia erionotae*	Banana skipper	Hawaii	E
1987	*Ooencyrtus erionotae*	Banana skipper	Hawaii	E
1988	*Dacnusa sibirica*	American leafminer	Holland	F
1988	*Encarsia formosa*	Greenhouse whitefly	Holland	F
1988	*Trichogrammatoidea bactrae fumata*	Litchi fruit borer	Thailand	E
1988	*Curinus coeruleus*	Jumping plantlice	Hawaii	F
1989	*Typhlodromus occidentalis*	Two-spotted spider mite	US	F
1989	*Phytoseiulus persimilis*	Two-spotted spider mite	US	S
1990	*Phytoseiulus persimilis*	Two-spotted spider mite	Australia	S
1990	*Nephaspis annicola*	Spiraling whitefly	Hawaii	F
1990	*Nephaspis bicoloc*	Spiraling whitefly	Hawaii	F

E: established; F: failure; S: successful